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Empirical Performance Evaluation of FSO Availability under Different Weather Conditions

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Abstract—**Free space optics (FSO), is an optical wireless communication (OWC) technology where transmission of data is carried by optical signals, *i.e., near infra-red (IR), LED, laser, IR-laser, etc.*, and the medium for signal propagation is free space. Although the subject received a lot of attention recently, communications via visible light have been of considerable interest in the field of research and military applications for many decades. FSO offers an unlicensed frequency spectrum, a larger bandwidth, very high data rates, less power consumption, easy deployability, high availability and most especially, capabilities towards 5G/5G+ requirements satisfaction. Focus of this research is on the evaluation of FSO availability empirically and statistically based on different weather conditions experienced in the West of Scotland. The empirical trails were conducted at different locations at the Paisley campus of the University of the West of Scotland (UWS). Later, statistical analysis was performed with reference to historical climate data to compare the results with the empirical findings. Our empirical results suggested the feasibility of FSO deployment for distances up to 100m, particularly suitable for inter-infrastructure wireless communications.**

Index Terms—**FSO propagation; OWC terrestrial transmission; visible light communication (VLC); empirical models.**

I. Introduction

A. Background

In most recent communication technologies, the focal point has become *wireless* because future generations of transmissions is expected to be guided effectively without any dedicated wave-guides. In present, microwave and radio frequencies (RF) are still on the job though, due to the bottleneck of licensed frequency spectrum, a better option is needed in order to aim smarter wireless networks more economically. However, as an alternative solution, optical wireless communication (OWC) takes part in nowadays as a suitable replacement for current wired infrastructures, *i.e., fibre optics*.

The OWC technology where used for terrestrial and space communications is known to be FSO. Because the spectrum used in free space optics (FSO) is unlicensed, this allows users to gain open source accessibility too. The data which has to be transmitted is modulated by optical carries in prior to propagation. In fact, the free space medium can be air, outer space, vacuum, etc., to be specific. Therefore, it finds this very useful whenever and wherever wired connectivity between transceivers is impractical. For example, during natural disaster recovery periods, *i.e., floods, etc.*, and highly mountainous rural areas, *i.e., Scottish highlands, etc.*, can be considered. Nevertheless, line of sight (LoS) between transmitter and receiver is strictly required for successful data transfer.

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B. Our Contribution

Research data analytics via empirical channel models play a significant role in performance evaluation of real case scenarios. In addition, it helps identify gaps in theoretical estimations and optimize link availability in future link establishments. Also, there was no empirical based study of FSO availability completed in the UK previously. Thus, our effort was to:

- Analyse FSO availability practically under different weather conditions available in the selected locations (UWS Paisley campus).
- Analyse additional atmospheric attenuations that affect FSO performance with reference to statistical historical weather data which the area (Paisley) is more prone to.
- Introduce FSO availability across the campus that can be extended geographically over the country for decision making in future deployments.

II. FSO Theory and Practice

FSO channels are typically used in very high speed applications. The frequency starts from 300GHz and currently it is capable of achieving 10Gbps. Furthermore, it is expected that it would extend up to 1.6Tbps in the future. Technically, the optical carrier is a very narrow beam, thus it reduces spatial requirements and Fresnel zones existence, and sends data over distances up to several kilometres, *i.e., 11km*.

A. Review of Literature

Apart from a number of merits FSO offers, there are some identified challenges on FSO propagation due to various phenomena that affect free space between transceivers and are uncontrollable. For example, physical obstructions like flying birds across the LoS can block the transmission signal for an instance. Moreover, scintillation, geometric losses that causes beam dispersion, pointing stability (building sway, wind, etc.), radiation, solar interference, atmospheric turbulence depending on temperature variations, weather impacts, absorption, etc., can degrade performance or result in total link outage. The characteristics about each phenomenon in detail can be referred in [1]- [6].

Consequently, climate and weather circumstances are the core factors which ground atmospheric attenuation. There are specific mathematical models, *i.e., Kim and Kruse, Al Naboulsi, Carbonneau, etc.*, to predict attenuations caused by

TABLE I
WEATHER CONDITIONS ON EMPIRICAL TRIAL DATES

Date 2017	Time (h)	Length (m)	Temperature (Celcius)	Weather
22.07	12.00-16.00	18.4	17	Rainy, cloudy, windy
22.07	13.00-17.00	35	17	Rainy, cloudy, windy
23.07	12.30-16.30	17.50	16	Rainy, cloudy, windy
24.07	14.00-18.00	29.26	25	Sunny, a little windy
25.07	12.45-16.45	20	11	Cloudy

fog, rain, haze, smoke, sandstorms, clouds and snow. In contrast, geographical losses, visibility, achievable distance and optical link budget are some of other parameters associated therewith. The relevant formulas can be referred in [3], [4], [6] and [7].

B. Advantages of Empirical Modelling

The ultimate target of this study introduces FSO availability via empirical findings across the selected areas and such modelling is useful because:

- Empirical results are fine references for link designers for permanent link installations in the future, in the same or similar areas that would avoid risks of link failures and unavailability.
- Practical solutions can be improved to optimize link performances.
- Statistical estimations along with empirical results are helpful to predict availability in disaster recovery situation can happen.

III. PERFORMANCE EVALUATION

A. Empirical Analysis

The empirical link trials took place for 5 days in 5 different locations at the campus area. The transceivers used operate in full duplex mode over two different wavelengths, 1330nm and 1550nm. In addition, the receiver sensitivity of the transceivers is (-23)dBm. Furthermore, one transmitter (10G-3-1) operates with an average power of 28.2351dB and the other transmitter (10G-3-2) operates with 32.2664dB. More information about the hardware can be referred in [9].

The Table I presents the weather conditions available during the trials and Fig. 1 visualizes resulted average availability (signal strength) in the designated locations.

The actual link lengths were less than 100m, and also trials were taken on ground level as the initial step. However, because statistical analysis is based on 100m channel length, empirical results were mathematically extrapolated to 100m for link budget (Rx power) comparisons. Fig. 2a and Fig. 2b illustrate the link budget for transceiver 10G3-1 and 10G3-2, respectively.

The results showed that despite rainy, cloudy and windy conditions available, the system performance was good enough to receive the transmission signal without vast attenuations. The average attenuation experienced was almost (-19.8716)dBm.

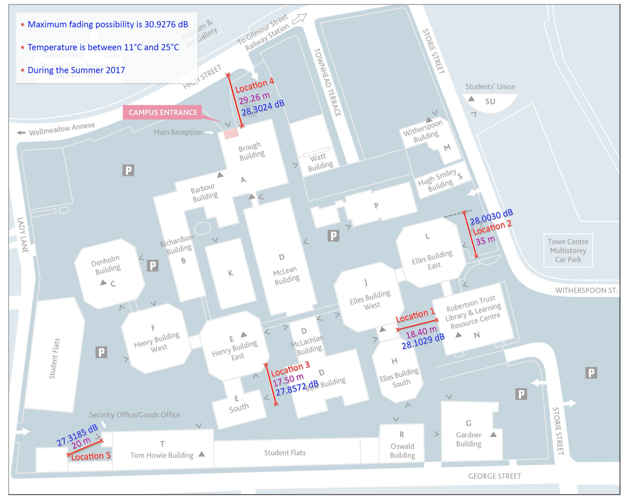

Fig. 1. Empirical FSO availability at UWS Paisley campus (UK).

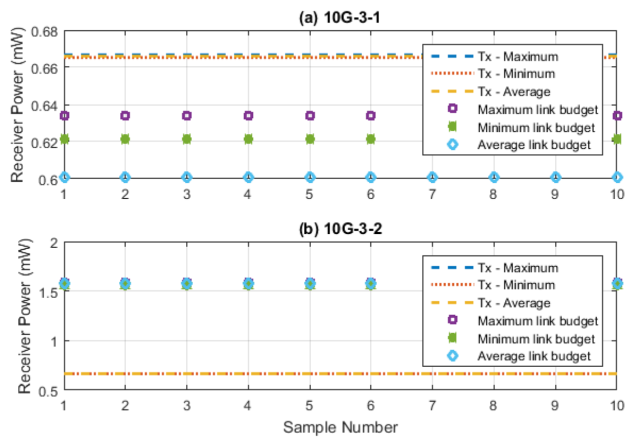

Fig. 2. Estimation of empirical link budget over 100m link length.

B. Statistical Analysis

This part of study was directly based on statistical historical weather data in Paisley (UK) (2016) [8] to estimate expectable weather attenuation margins in the town annually. To gain predictions, statistical records, *i.e., monthly rainfall rates, monthly snowfall rates, etc.*, were substituted to mathematical equations straight-away. For that, Kim and Kruse models were used as those are known to be less complex and more accurate mathematically.

Particularly, the records [8] confirmed that the town is not affected by heavy fog which results in less than 100m visibility. Therefore, fog was not considered in average and maximum link budget calculations. According to the equipment specifications [9], fog attenuation is 10dB if visibility of the free space is 50m or less. Hence, it was taken into account in the worst case scenario (minimum link budget) as it is within 100m of channel length. The general equation for optical link budget calculation is given as:

$$P_{\text{rx}} = P_{\text{tx}} - P_{\text{total attenuation}} \tag{1}$$

TABLE II
SUMMARY OF THE EMPIRICAL AND THE STATISTICAL LINK BUDGET CALCULATIONS

Optical Link Budget Difference			
Category	Empirical (dB)	Statistical (dB)	Deviation (dB)
10G-3-1 Transceiver			
Minimum	27.7865	27.8129	5.6379
Average	27.9321	27.8927	7.4895
Maximum	28.0222	27.8928	12.6992
10G-3-2 Transceiver			
Minimum	31.9325	32.1046	17.9988
Average	31.9829	32.1345	17.4881
Maximum	31.9982	32.1344	17.0304

Fig. 3 shows annual statistical snow attenuation depending on wet or dry snow state. Likewise, statistical calculations were made for annual rain attenuation and link budget estimations.

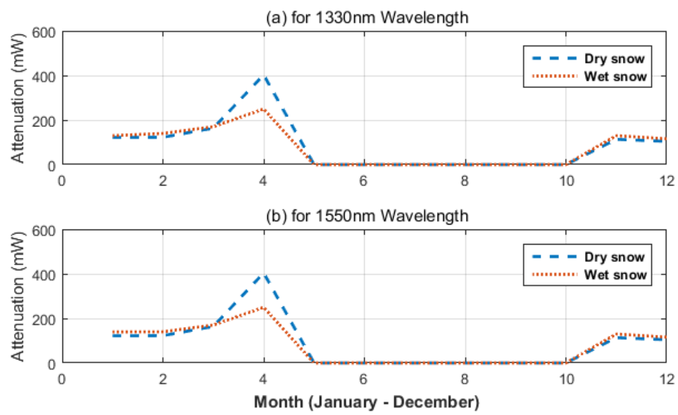

Fig. 3. Estimation of annual snow attenuation.

IV. DISCUSSIONS

Table II summarizes available link budgets and deviations in both analytics.

It can be seen clearly that the received power is almost as same as the transmitted power in both studies. Undoubtedly, deviations between the analyses are extremely low. Therefore, a very high availability can be expected in Paisley (UK) throughout the year, thus, this verifies the area is well suitable for permanent FSO transmission for distances may be limited up to 100m in spite of weather instability. Although empirical results were not affected by snowfall and fog, statistical evaluation with snow and fog attenuations confirmed that high availability is potentially achievable in the area. However, relatively lower link budget during empirical trials is due to following unavoidable circumstances:

- Sensitive beam reflections by tiny particles i.e., grass, etc., in the LoS.
- Mechanical tightness issues of the transceivers due to heavy wind that would have caused loss of finest optical alignment.
- Neglect system losses due to hardware and cables.

Regarding geographical distribution in the UK, higher availability can be expected in England and Wales due to relatively stable climate conditions. On the other hand, snow attenuation can noticeably affect in Scottish highlands due to much higher snowfall rates. Approximately, same performance like in the West of Scotland can be expected in Northern Ireland because of similar weather status.

Nevertheless, some research areas are still remaining to be focused empirically for confirming some reciprocal conclusions in theory based studies. For example, a study [6] states that the maximum density of FSO strength can be gained just above the surface of earth due to gravitational force, while another [4] specifies that troposphere regions have the most attenuation. However, noticeable fluctuation of signal strength may be detectable in long height from ground level because of gradual decrease of gravity, cloud appearance and wind.

V. CONCLUSION

As a demanding wireless technology towards 5G/5G+ network requirements yet to commercially be available by 2020, FSO is becoming more popular in terrestrial and space communications. Due to a number of advantages as well as challenges mentioned in the sections I and II, further comprehensive empirical trials are needed in order to make sure about its merits as well as invent ways to mitigate impacts that limit functionalities. In this study, empirical trials were carried out in UWS Paisley campus during the summer 2017, and then annual availability was analysed with reference to historical weather recorded in 2016 [8]. The overall outcome of the research concludes that FSO has robustness to handle successful wireless communication during usual weather conditions in the UK throughout the year for link length of up to 100m.

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